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Critical Number of The Orbital Stability of Planets Trapped in First-Order Mean-Motion Resonances

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We study the stability of planets in the first-order mean-motion resonances with numerical simulations.

Nowadays, 27 systems and 158 candidate systems that are composed of multi super-Earth or Neptunes are observed (e.g., Borucki et al. 2011). These planets are close to the central star ($\lesssim 0.05$AU). Only 4% of systems have orbital periods which are almost commensurable with neighboring planets within 1% period ratio. This suggests that most of planets are not in mean-motion resonances.

Orbital migration is probable mechanism for their origins. When a protoplanet is formed in the gas disk, the protoplanet migrate toward its central star due to the interaction with the gas disk. The migration is stopped when the protoplanet arrives at the inner edge of the gas disk. In the situation that many protoplanets are formed, protoplanets are captured at the location of the mean-motion resonance (Terquem & Papaloizou 2007, Ogihara & Ida 2009). In the case of N-body simulations with standard type-I migration, planets stay stable more than 10^8 Kepler time. In the case of N-body simulations with weaker type-I migration, planets become unstable after gas depletion. Through collisions and merges of planets, finally about 5 planets are in large separations ($\sim$ 19 Hill radius).

Although the stability time of the planets systems that are not in resonances is empirically known (e.g., Chambers et al., 1996), the stability time of planets in the mean-motion resonance is not well known. To clarify what is most responsible to make systems offset from the resonances, we calculate the stability of first-order mean-motion resonant systems. We put on innermost planet at 0.1AU and put the other planets on $p + 1$:p resonant orbits . We find when number of planes is more than some critical number, crossing time decreases rapidly, while crossing time decrease continuously in non-resonant system. We examine the dependence of critical number with changing orbital separations, and planetary mass.

Exoplanetary systems whose planets are not in mean-motion resonance is formed by the scenario that planets over critical number are trapped in resonances and these planets cause orbital instability after gas depletion.